INSTITUTE OF PAPER CHEMISTRY
Appleton · Wisconsin

GENERAL

A STUDY OF MEANS TO OPTIMIZE STRENGTH AND DRAINAGE PROPERTIES IN LINERBOARD

Project 3021

Report One

A Progress Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

January 7, 1972

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SUMMARY

The overall program on Project 3021 is concerned with means of improving the strength of unbleached kraft primary liner stock without sacrifice in drainage and water removal properties. Due to difficulties in procuring satisfactory commercial pulps, initiation of the laboratory work was delayed three to four months. However, some exploratory studies have been completed in Phases I-A and -B of the program and the results are reported herein.

In work completed thus far in Phase I-A, a commercial liner pulp equivalent to stuff box stock was disk refined in an effort to produce a 20-25% improvement in bursting strength over that of the same pulp drawn from the mill headbox. The refining was carried out in steps so as to provide samples ranging in equilibrated freeness from 340-640 ml. C.S.F. Freeness was observed to increase about 100 ml. over a period of several days after refining and, hence, the equilibrated values were recorded. This would correspond to the mill samples which aged about one week in transit. Handsheets equivalent to 42-lb. liner were prepared from each refining interval and from the mill stuff box and headbox samples under constant conditions of temperature, time, and rate of agitation in the Rapid-Köthen sheet mold. In each case, sets were formed in tap water with and without 0.0375% of mill rosin and 1% of alum at pH 6. Measurements were made of drainage rate, filtration resistance, and sheet strength properties.

The presence of the small amount of rosin-alum sizing was found to have a negligible effect on the strength properties of the mill stuff box stock and only a slightly adverse effect on the bursting strength of the refined pulps. The sizing

agent also had a negligible effect on the drainage rate and filtration resistance of all samples with the exception of the lowest freeness pulp (340 ml. C.S.F.) in which case the sizing agent increased the filtration resistance. The sample refined to 635 ml. C.S.F. was found to have drainage and strength properties roughly comparable to the mill headbox stock which had an equilibrated freeness of 640 ml. C.S.F.

Maximum bursting strength was obtained at an equilibrated freeness level of 435 ml. C.S.F. where an increase of 28% over the mill headbox stock was attained in the absence of rosin and alum; the increase was 22% in the presence of the sizing agent. As would be expected, the drainage rate of this pulp was significantly lower, and the filtration resistance greater, than that of the mill headbox stock. A second series of refiner trials was subsequently made in an effort to provide more adequate supplies of the reference pulp (equivalent to the mill headbox stock) and the maximum bursting strength pulp for subsequent study of means to improve drainage properties.

A preliminary screening of beater adhesives under Phase I-B of the program revealed that incorporation of 2% of a commercial polyacrylamide resin or 2% of a polyamide-polyamine wet strength agent into the mill stuff box stock increased bursting strength to a level which was 22-29% over that of the mill headbox stock. The drainage rate in the presence of these additives was roughly comparable to, or slightly less than, that of the mill headbox stock. Several other additives improved the bursting strength of the stuff box stock but the levels attained were only marginally better than that of the headbox stock. Further examination of beater adhesives will be made.

The use of the Rapid-Köthen sheet mold for studying water removal properties was found to be inadequate and was abandoned. It is planned to use the Institute's Web Former for studying water removal after having established optimum conditions for drainage and strength development.

INTRODUCTION

This is Progress Report One on Project 3021 established in cooperation with the Fourdrinier Kraft Board Institute, Inc. for the purpose of studying means of improving both the drainage and strength properties of high-yield kraft liner pulp. Improved drainage would permit the use of higher yield pulping methods for domestic board and increased strength is of interest to those mills supplying linerboard to the European market. European linerboard is made at a substantially higher bursting strength than current domestic board and, hence, the domestic stock must be refined to a significantly greater extent to meet the strength requirement. The increased refining slows drainage and reduces production. The goal of the current program is the attainment of a 20-25% increase in the bursting strength of the primary stock with no reduction in drainage rate and water removal.

Three approaches to the problem are considered in Phase I of the program. The first of these considers the combination of refining and drainage aids, the second examines the effect of beater adhesives on the faster draining stuff box stock, and the third approach considers combinations of refining, beater adhesives, and drainage aids.

Theoretical considerations for the use of drainage aids in papermaking systems were presented in Progress Report One on Project 2926. The method adopted in the earlier work for studying drainage in liner stock was a Rapid-Kothen sheet mold equipped with vacuum drainage and a vacuum gage such that drainage could be measured in terms of time and pressure after subjecting the fiber suspension to several degrees of agitation. The same equipment is being utilized in the present work.

The mechanism of improved strength through the use of beater adhesives was investigated by Leech (1). This investigator found that of the overall strength improvement from locust bean gum, 15% was due to increased bonded area, 25% to improved formation, and 60% to increased bonding strength. However, it is well established that beater adhesives differ in their effectiveness depending upon the type of pulp involved, the extent of refining, and the environmental conditions under which they are utilized. Locust bean gum tends to improve formation at the levels normally used in papermaking whereas the starches generally do not. Many beater adhesives are responsive to light-to-moderately beaten bleached kraft and sulfite pulps but their effectiveness is generally diminished in very lightly refined unbleached kraft pulps where a relatively low surface area for adsorption is available. This factor may be further complicated in commercial liner pulp by high yield and liquor retention. The present program considers selected beater adhesives which have been indicated to show some effectiveness in unbleached kraft pulps and it explores the possibility of utilizing partially cooked starch as a means of spanning the relatively great distances between fibers in lightly refined pulps as advocated by Casey (2).

EXPERIMENTAL

PROCESSING OF PULPS

Two samples of high-yield unbleached kraft primary liner pulps and samples of the mill rosin size and alum were provided for the experimental program by Great Northern Paper Company at Cedar Springs, Ga. The pulps included approximately 200 gallons of refiner stock which was roughly equivalent to the mill stuff box pulp and is referred to as stuff box stock in this report. Ten gallons of the mill headbox stock containing 0.0375% of rosin size and 1% of alum (based on fiber) were also supplied for the program. These pulps were shipped in the presence of a preservative and were stored at 40°F. upon arrival at the Institute. The stuff box stock was free of added materials save for the preservative. The consistency of the stuff box stock was 5%, the freeness was 740 ml. C.S.F., and the pH was 9.0. The consistency of the headbox stock, as received, was 0.6%, the freeness was 640 ml. C.S.F., and the pH was 8.5. These measured freeness values were said to be approximately 100 cc. higher than those measured at the time the supplies were drawn from the mill system. The pH of the stuff box stock was considered typical but the pH of the headbox stock was well above the normal level of 6. An increase in freeness level is sometimes observed in refined pulps upon standing and the reversion in pH indicated in the headbox stock is attributed to residual alkali in the high-yield kraft pulp. Because of the uncertainty in the initial freeness of the mill stuff box and headbox stocks, the decision was made to use the equilibrated freeness values in the present work.

A portion of the stuff box stock equivalent to 20 lb. of fiber was diluted to 2.5% consistency with tap water and then refined on the Institute's 36-inch disk refiner. The dilution was necessary to permit pumping of the stock with the equipment available. The refiner was operated at zero clearance and samples were collected after 2, 3, 4, and 6 passes to provide a range in freeness from 340 to 635 ml. C.S.F. These freeness values were recorded after the refined pulp had aged 1-2 days at room temperature and little or no change was indicated thereafter. As with the stuff box and headbox samples, freeness measured immediately after refining was approximately 100 ml. lower than that indicated but the equilibrated values were used for the reason given previously. The refined pulps were stored at 40°F. until used in handsheets and filtration resistance measurements.

A second series of refiner runs was made with the stuff box stock after handsheets had been prepared from the first series and conditions had been established which produced:

1. a pulp corresponding to the mill headbox stock in strength and drainage properties, and
2. a pulp having a 20-25% higher bursting strength than that afforded by the mill headbox stock.

The purpose of the second series was to provide adequate supplies of pulp for the more extensive study of strength, drainage, and water removal properties. The operation of the disk refiner in the second series was essentially the same as that in the first and samples were collected at equilibrated freeness levels of 630 and 460 ml. C.S.F.

HANDSHEET PREPARATIONS AND DRAINAGE TESTS

Handsheets were prepared from the mill stuff box and headbox stocks and from the disk refined pulps using the Rapid-Kothen sheet mold equipped with vacuum drainage, vacuum gage, and mechanical stirrer as described in Progress Report One on Project 2926. Three sets were formed from the mill stuff box stock; one set at pH 9 (as received) and two sets at pH 6 using sulfuric acid in one case and rosin-alum size in the second case. One set was formed from the mill headbox stock at pH 6 using sulfuric acid for pH adjustment. Two sets were prepared from each of the disk refined pulps; one with and the other without rosin-alum sizing. All of these sets were formed at pH 6 using sulfuric acid for the final pH adjustment. The amount of rosin and alum used in the sized sets was the same as that used in the mill system, i.e., 0.0375% of rosin and 1% of alum based on weight of fiber.

For each set of sheets the equivalent of 100 g. of pulp was metered into a stainless steel drum containing sufficient tap water to provide an approximate fiber consistency of 0.1%. The temperature was adjusted to 25°C. in all cases. The required amounts of rosin, alum, and/or sulfuric acid were added allowing five minutes of stirring for each. The final fiber consistency was exactly 0.1%. A 6-liter aliquot of the pulp (nominally equivalent to 42-lb. liner) was then metered into the Rapid-Köthen mold where it was agitated for 10 seconds at a rate of 260 cycles/min. The stirrer was then stopped and the drainage process started simultaneously. The time required for drainage and the maximum and stabilized vacuum levels were recorded. This process was repeated to obtain average values for the drainage times and vacuum levels. Hence, drainage properties in the sheet mold were measured with a constant volume of 0.1% pulp. The webs formed in this manner also served as basis weight sheets to determine the actual volume of pulp required to produce a sheet equivalent to 42-lb. liner. Thirteen sheets were then formed using the corrected volume; six sheets for water removal determinations and seven for physical strength tests. Of the six sheets for water removal, two were removed from the wire without pressing and four were pressed at 50 p.s.i. (gage) between blotter stock for a specified time, i.e., two sheets for 15 sec. and two sheets for 6 min. The fiber solids contents of these sheets were determined after taking to dryness. The seven sheets for strength tests were removed from the wire by couching onto blotters and were then pressed between blotters at 50 p.s.i. for 5 min. followed by drying for 7 min. on a steam-heated drum in contact with one blotter. Sheets prepared in this manner were tested for basis weight, caliper, density, Elmendorf tear, Mullen bursting strength, modified ring compression, and tensile strength. All strength test results were corrected to 42-lb. basis weight.

Samples of each of the aforementioned pulps were submitted for filtration resistance measurements. The concept of an average specific filtration resistance was defined by Ingmanson (3) for compressible materials. Ingmanson applied Darcy's law to the particular case of compressible materials for either constant-pressure or constant-rate filtration. For the case of constant rate, this resistance is defined by the expression

$$R = \frac{\Delta P}{\theta} \frac{A^2 \rho g}{\mu c (dV/d\theta)^2}$$

where

R = the average specific filtration resistance, cm./g.

ΔP = pressure drop, cm. water

θ = filtration time, sec.

A = cross-sectional area of flow, cm.^{2}

ρ = fluid density, g./cc.

g = gravitational acceleration, cm./sec.^{2}

μ = fluid viscosity, poises

$dV/d\theta$ = volumetric flow rate, cc./sec.

c = consistency, g./cc.

The filtration test is a simple, reliable operation which is performed under reproducible conditions of constant rate with a very dilute slurry (0.01% consistency). The filtration data necessary are the filtration conditions of flow rate, slurry consistency, and filtrate temperature plus the time-pressure drop relationship at these conditions.

The fibers are deposited on a septum which has negligible resistance at the established flow rates. The collected fibers are dried and weighed, and, since the volume is known from the rate and time, the consistency is established precisely.

Sheet mold drainage and water removal properties are recorded in Table I and the filtration resistance results are given in Table II. Filtration resistance as a function of pressure drop is shown in Fig. 1 and 2. Physical strength results are recorded in Table III.

Handsheets were also formed from the second refining series of pulps under identical conditions to those previously described. However, these sets and most subsequent sets were limited to the rosin-alum sized condition since the sizing agent was found to have little or no effect on drainage rate and filtration resistance properties at these freeness levels and since the commercial liner normally contains size. Water removal properties were not determined. Drainage and strength test results for these sets are summarized in Table IV. Filtration resistance data will be included in a subsequent report.

Handsheets intended to screen the effectiveness of selected beater adhesives were prepared from the mill stuff box stock under the same general conditions. Two percent (based on fiber) of the beater adhesive was incorporated

TABLE I

THE EFFECT OF REFINING ON THE DRAINAGE PROPERTIES OF UNBLEACHED KRAFT LINER PRIMARY PULP

Set No.	Description	Drainage Time, sec.	Drainage Rate, ml./sec.	Max. Vacuum, mm.	Stabilized Vacuum Level, mm.	Solids in Web, %: Off Wire	Solids in Web, %: After Wet Pressing at 50 p.s.i.: 15 sec.	Solids in Web, %: After Wet Pressing at 50 p.s.i.: 6 min.
1	Stuff box stock, as is, 740 ml. C.S.F., pH 9	6.1	984	40	40	6.7	33.7	35.1
2	Stuff box stock, sulfuric acid added to pH 6	6.2	968	35	35	6.3	33.6	34.4
3	Stuff box stock, rosin and alum added, pH 6	6.2	968	40	40	6.6	33.2	34.7
4	Headbox stock, 640 ml. C.S.F. (contains rosin and alum as received) sulfuric acid added to pH 6	6.4	938	45	45	7.2	33.4	33.4
5	Stuff box stock refined to 635 ml. C.S.F., sulfuric acid added to pH 6	6.7	896	50	40	7.4	31.2	31.8
6	Stuff box stock refined to 635 ml. C.S.F., rosin & alum added, pH 6	6.7	896	50	40	7.3	31.6	32.7
7	Stuff box stock refined to 530 ml. C.S.F., sulfuric acid added to pH 6	8.2	732	115	55	9.3	31.6	32.6
8	Stuff box stock refined to 530 ml. C.S.F., rosin & alum added, pH 6	8.2	732	110	50	9.5	32.2	32.7
9	Stuff box stock refined to 435 ml. C.S.F., sulfuric acid added to pH 6	10.3	583	205	60	10.6	31.7	33.5
10	Stuff box stock refined to 435 ml. C.S.F., rosin & alum added, pH 6	10.3	583	195	60	10.4	31.7	31.6
11	Stuff box stock refined to 340 ml. C.S.F., sulfuric acid added to pH 6	18.3	328	330	110	12.2	31.6	33.5
12	Stuff box stock refined to 340 ml. C.S.F., rosin & alum added, pH 6	19.1	314	325	110	12.1	31.7	33.0

Notes: The amount of rosin and alum added in Sets 3, 6, 8, 10, and 12 is equivalent to that contained in the mill headbox stock; i.e., 0.0375% of rosin size and 1.0% of alum (based on fiber).

The freeness values listed above for the refined pulps were measured after the samples had been allowed to stand at room temperature for one to two days.

TABLE II

THE EFFECT OF REFINING ON THE FILTRATION RESISTANCE
OF UNBLEACHED KRAFT LINER PRIMARY PULP

Set No.	Description	Filtration Resistance, R x 10^{-8}, cm./g. — Pressure Drop ΔP, cm. H_2O: 10	20	30	40	50	60	70	80	90
1	Stuff box stock, as is, 740 ml. C.S.F., pH 9	0.27	0.38	0.46	0.54	0.61	0.68	0.75	0.82	0.87
2	Stuff box stock, sulfuric acid added to pH 6	0.23	0.33	0.41	0.48	0.55	0.61	0.67	0.73	0.78
3	Stuff box stock, rosin & alum added, pH 6	0.24	0.34	0.42	0.50	0.56	0.63	0.69	0.75	0.81
4	Headbox stock, 640 ml. C.S.F. (contains rosin & alum as received) sulfuric acid added to pH 6	0.58	0.88	1.14	1.38	1.60	1.82	2.03	2.23	2.43
5	Stuff box stock refined to 635 ml. C.S.F., sulfuric acid added to pH 6	0.70	1.03	1.32	1.56	1.81	2.05	2.27	2.49	2.70
6	Stuff box stock refined to 635 ml. C.S.F., rosin & alum added, pH 6	0.63	0.94	1.21	1.45	1.67	1.88	2.09	2.28	2.48
7	Stuff box stock refined to 530 ml. C.S.F., sulfuric acid added to pH 6	1.35	2.08	2.73	3.32	3.89	4.43	4.95	5.49	5.95
8	Stuff box stock refined to 530 ml. C.S.F., rosin & alum added, pH 6	1.42	2.15	2.80	3.40	3.96	4.50	5.02	5.52	6.02
9	Stuff box stock refined to 435 ml. C.S.F., sulfuric acid added to pH 6	2.12	3.29	4.32	5.30	6.21	7.10	7.95	8.79	9.59
10	Stuff box stock refined to 435 ml. C.S.F., rosin & alum added, pH 6	2.01	3.27	4.32	5.29	6.21	7.10	7.96	8.78	9.58
11	Stuff box stock refined to 340 ml. C.S.F., sulfuric acid added to pH 6	4.04	6.26	8.31	10.3	12.1	13.9	15.6	17.4	19.1
12	Stuff box stock refined to 340 ml. C.S.F., rosin & alum added, pH 6	4.40	6.97	9.30	11.5	13.7	15.7	17.7	19.7	21.6

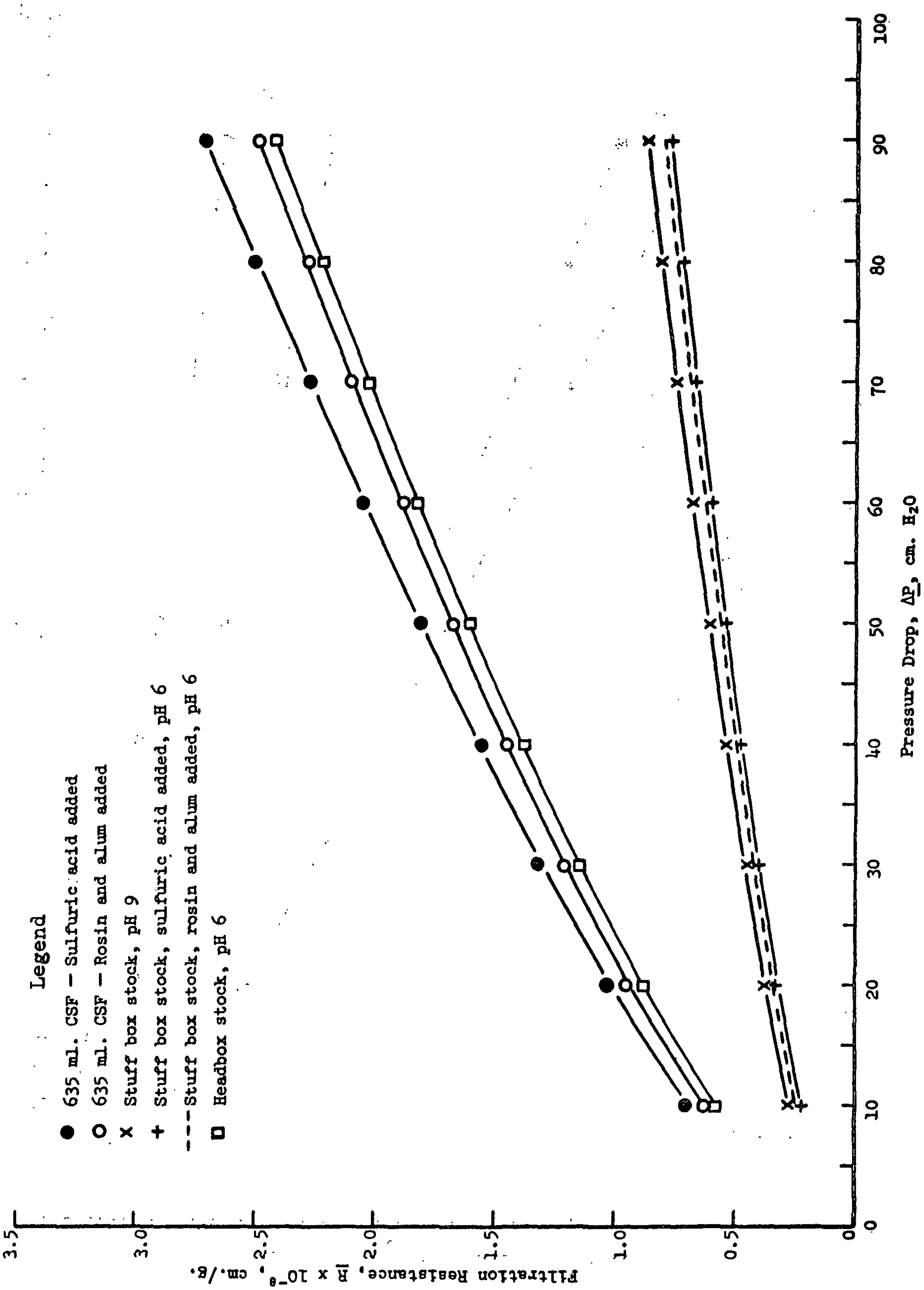

Figure 1. Filtration Resistance as a Function of Pressure Drop

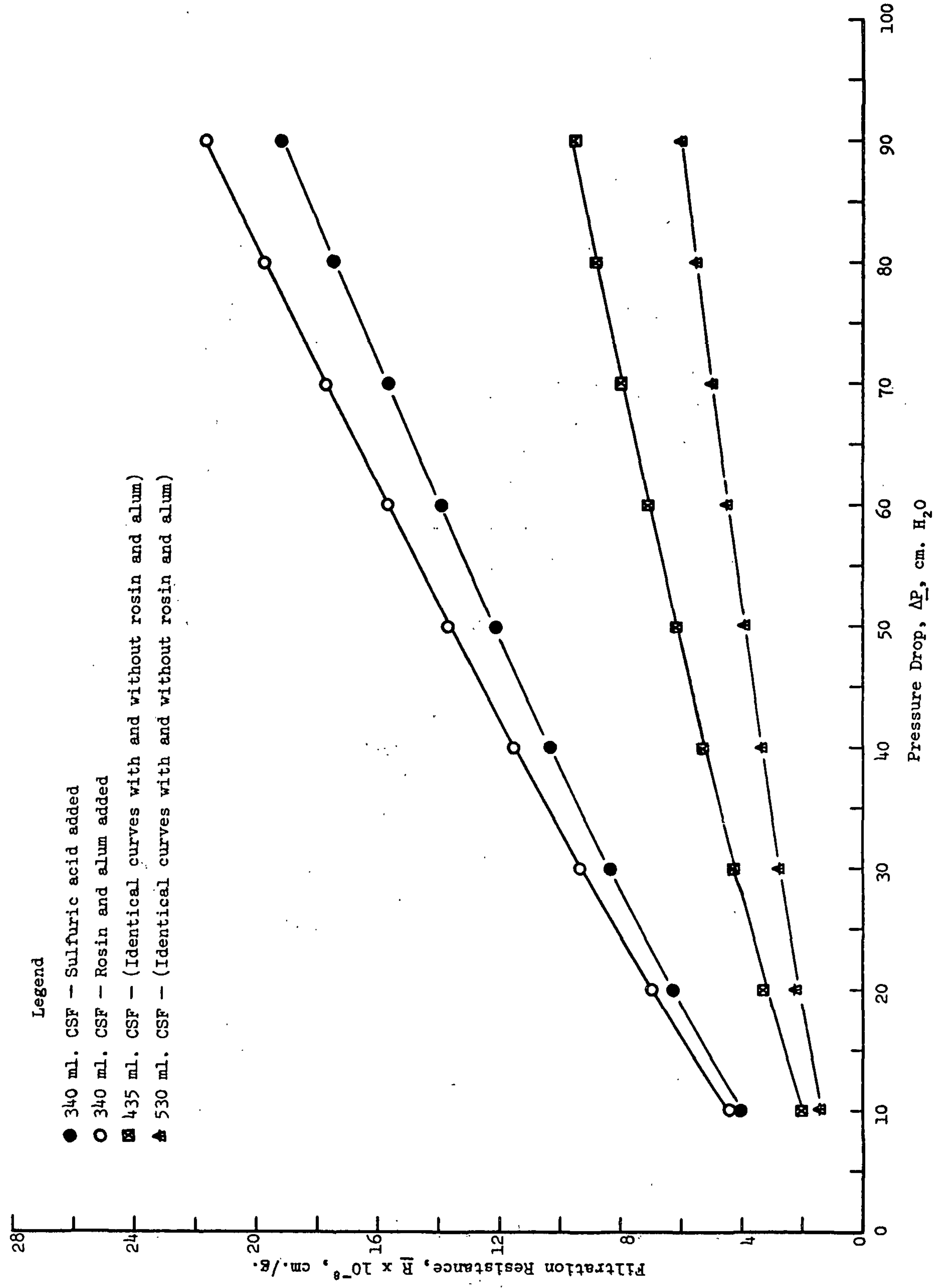

Figure 2. Filtration Resistance as a Function of Pressure Drop

TABLE III

THE EFFECT OF REFINING ON THE STRENGTH PROPERTIES OF UNBLEACHED KRAFT LINER PRIMARY STOCK

FIRST REFINING SERIES

Set No.	Description	Basis Wt. lb./M ft.²	Caliper, mils	Apparent Density	Elmendorf Tear, g./sheet	Corrected Tear, (42-lb. basis)	Jumbo Mullen Bursting Strength, p.s.i.g.	Corrected Mullen, (42-lb. basis)	Modified Ring Compression, lb./in.	Corrected Ring Compression, (42-lb. basis)	Tensile, lb./in.	Corrected Tensile (42-lb. basis)
1	Stuff box stock, as is, 740 ml. C.S.F., pH 9	43.5	20.8	2.1	344	332	83	80	16.5	15.9	37.5	36.2
2	Stuff box stock, sulfuric acid added to pH 6	43.4	20.5	2.1	341	330	79	76	15.7	15.2	36.1	34.9
3	Stuff box stock, rosin & alum added, pH 6	43.4	19.5	2.2	352	341	82	79	15.3	14.8	36.2	35.0
4	Headbox stock, 640 ml. C.S.F. (contains rosin & alum as received), sulfuric acid added to pH 6	43.6	18.5	2.4	362	349	114	110	19.9	19.2	48.0	46.2
5	Stuff box stock refined to 635 ml. C.S.F., sulfuric acid added to pH 6	45.2	16.9	2.7	402	374	119	111	20.3	18.9	49.2	45.7
6	Stuff box stock refined to 635 ml. C.S.F., rosin & alum added, pH 6	44.1	16.5	2.7	390	371	116	110	19.6	18.7	51.3	48.9
7	Stuff box stock refined to 530 ml. C.S.F., sulfuric acid added to pH 6	45.7	14.8	3.1	435	400	138	127	22.2	20.4	58.1	53.4
8	Stuff box stock refined to 530 ml. C.S.F., rosin & alum added, pH 6	43.9	15.0	2.9	402	385	125	120	21.4	20.4	58.3	55.8
9	Stuff box stock refined to 435 ml. C.S.F., sulfuric acid added to pH 6	43.2	13.5	3.2	366	356	145	141	22.8	22.2	62.4	60.7
10	Stuff box stock refined to 435 ml. C.S.F., rosin & alum added, pH 6	43.4	13.7	3.2	358	346	139	134	21.7	21.0	57.9	56.0
11	Stuff box stock refined to 340 ml. C.S.F., sulfuric acid added to pH 6	43.3	12.2	3.5	357	346	131	127	22.7	22.0	60.4	58.6
12	Stuff box stock refined to 340 ml. C.S.F., rosin & alum added, pH 6	43.6	12.9	3.4	379	365	128	123	25.0	24.0	60.3	58.1

TABLE IV

THE EFFECT OF REFINING ON THE DRAINAGE AND STRENGTH PROPERTIES OF UNBLEACHED KRAFT LINER PRIMARY STOCK

SECOND REFINING SERIES

Set No.	Description	Drainage Time, sec.	Drainage Rate, sec.	Maximum Vacuum, mm.	Stabilized Vacuum Level, mm.	Basis Wt., lb./M ft.^{2}	Caliper, mils	Apparent Density	Elmendorf Tear, g./sheet
13	Stuff box stock refined to 630 C.S.F., rosin & alum added, pH 6	6.7	896	55	40	43.4	16.3	2.7	386
14	Stuff box stock refined to 460 C.S.F., rosin & alum added, pH 6	9.5	633	180	55	43.5	14.3	3.0	389

Set No.	Description	Corrected Tear, (42-lb. basis)	Jumbo Mullen Bursting Strength, p.s.i.g.	Corrected Mullen, (42-lb. basis)	Modified Ring Compression, lb./in.	Corrected Ring Compression, (42-lb. basis)	Tensile, lb./in.	Corrected Tensile, (42-lb. basis)
13	Stuff box stock refined to 630 C.S.F., rosin & alum added, pH 6	374	114	110	19.4	18.8	46.3	44.8
14	Stuff box stock refined to 460 C.S.F., rosin & alum added, pH 6	373	136	131	21.5	20.7	58.2	56.2

into the pulp either before or after the addition of rosin and alum. Once again, five minutes stirring time was allowed between additions. The following beater adhesives were included: polyacrylamide resins (Accostrength resins 90, 93, and 95 — American Cyanamid Company), fully dispersed and partially dispersed cationic potato starch (Sta-Lok 400 — A.E. Staley Mfg. Co.), guar gum (Jaguar — Stein, Hall & Co., Inc.), and a wet strength resin (Kymene 557 — Hercules, Inc.). The Accostrength resins were diluted to 1% solids and were then added to the pulp after the rosin and alum. The cationic starch was dispersed at 5% solids in tap water by cooking over steam for 30 minutes at 95°C. The suspension was diluted to 1% solids and was added to the pulp before the rosin-alum in one set of sheets and after the rosin-alum in a second set. Partially dispersed cationic potato starch was prepared by heating the 5% aqueous slurry for 30 minutes at 70-75°C. followed by rapid cooling to room temperature and dilution to 1% solids. A 1:1 blend of fully dispersed and partially dispersed potato starch was also examined. The partially dispersed material and the blend were added prior to the rosin and alum. Guar gum was dispersed at 0.5% solids in tap water by cooking over steam for 30 minutes at 95°C. employing vigorous agitation. Kymene 557 was diluted with tap water to 0.1% solids for addition to pulp. Guar gum and Kymene were added before the rosin and alum.

Water removal properties were not determined on these sheets and the filtration resistance data for selected sets will be included in a subsequent report. The sheet mold drainage data and the physical strength results are recorded in Table V.

TABLE V

A COMPARISON OF BEATER ADHESIVES IN STUFF BOX STOCK AT THE 2% ADDITION LEVEL

Set No.	Beater Adhesive	Drainage Time, sec.	Drainage Rate, ml./sec.	Maximum Vacuum, mm.	Stabilized Vacuum Level, mm.	Basis Wt., lb./M ft.^{2}	Caliper, mils	Apparent Density	Elmendorf Tear, g./sheet	Corrected Tear, (42-lb. basis)	Jumbo Mullen Bursting Strength, p.s.i.g.	Corrected Mullen, (42-lb. basis)	Modified Ring Compression, lb./in.	Corrected Ring Compression, (42-lb. basis)	Tensile, lb./in.	Corrected Tensile (42-lb. basis)
3	Stuff box control	6.2	968	40	40	43.4	19.5	2.2	352	341	82	79	15.3	14.8	36.2	35.0
4	Mill headbox stock (control)	6.4	938	45	45	43.6	18.5	2.4	362	349	114	110	19.9	19.2	48.0	46.2
15	Accostrength 90[a]	6.8	882	40	35	43.4	18.0	2.4	398	385	147	142	19.2	18.6	54.6	53.1
16	Accostrength 93[a]	6.4	938	40	35	44.5	19.4	2.3	418	395	123	116	19.1	18.0	46.8	44.2
17	Accostrength 95[a]	6.4	938	40	35	44.7	19.5	2.3	442	415	117	110	19.0	17.8	51.6	48.5
18	Dispersed cationic potato starch	6.4	938	40	35	44.6	19.3	2.3	421	396	119	112	21.0	19.8	49.0	46.1
19	Dispersed cationic potato starch (reverse order of addition)[a]	6.5	923	40	35	44.5	19.5	2.3	432	408	120	113	18.3	17.3	54.4	51.3
20	Partially dispersed cationic potato starch	6.2	968	40	35	44.6	19.8	2.3	418	394	113	106	17.5	16.5	43.4	40.9
21	1:1 Blend by wt. of partially & fully dispersed potato starch	6.4	938	40	35	44.1	19.1	2.3	406	387	112	107	17.6	16.8	47.4	45.1
22	Guar gum	6.3	952	40	35	43.2	18.6	2.3	432	420	111	108	17.4	16.9	44.3	43.1
23	Kymene 557	6.2	968	40	35	43.4	18.3	2.4	408	395	139	135	21.3	20.6	55.5	53.7

[a]The order of addition in these sets was rosin size, alum, sulfuric acid, and beater adhesive.
The order of addition in all other sets was beater adhesive, rosin size, alum, and sulfuric acid.

Note: All sets were formed at pH 6 in the presence of 0.0375% of rosin size and 1% of alum (based on fiber). The rate of agitation in the sheet mold was 260 cycles/min. in all cases.

DISCUSSION OF RESULTS

The sheet mold drainage time and the filtration resistance data for the stuff box, headbox, and disk-refined pulps (Tables I and II; Fig. 1 and 2) show essentially parallel trends. In general, drainage rate decreased and filtration resistance increased as refining progressed with the most dramatic change occurring between the 435 and 340 freeness levels. The effect of rosin and alum on these properties is shown to be negligible except at the lowest freeness level (Sets 11 and 12) where the presence of the sizing agent slowed drainage. The apparent insensitivity of the drainage properties to the sizing agent may be due to the relatively low addition level. Somewhat more substantial differences in drainage properties might be expected at higher size additions and lower pH levels.

The water removal data in Table I exhibit what might be considered a reversal from expected behavior in that the more highly refined pulps held substantially less water coming off the wire than the stuff box and headbox stocks. However, these results may be misleading since the most highly refined pulp required three times as long to drain as the stuff box stock and it was under much higher vacuum during that time. These data serve to show the inadequacy of the sheet mold method for measuring water removal properties and it was for this reason that further testing was abandoned. Water removal could be measured at a constant drainage time such as would be afforded by a moving web. Hence, it is planned to measure this property on selected pulps on the Institute's Continuous Web Former after the optimum conditions for strength and drainage have been established.

The results in Table III show that maximum bursting strength was attained at the 435 freeness level (Sets 9 and 10) in which case improvements of 22-28% were achieved over the mill headbox controls. As would be expected, the 435 freeness pulp also shows notably higher filtration resistance and reduced drainage rate compared to the headbox reference pulp. Ring compression and tensile strength appear to reach maximum at either the 435 or 340 freeness levels depending upon the presence of sizing agent. In general, bursting strength is marginally lower in the presence of rosin and alum while the other strength properties do not show a consistent trend in this regard. The tearing strength results obtained in this series, though not of primary concern to the program, are quite noteworthy. Tear is indicated to reach a maximum at the intermediate refining interval (Sets 7 and 8) rather than at one of the lower levels as would normally be expected. In fact, the tear resistance at the lowest freeness level is equal to, or greater than, that of the stuff box stock. Hardwood pulps are known to increase in tear strength with refining but the result was not expected with the present pulp which contained only 2-3% of mixed hardwoods. A plausible explanation for this behavior is not apparent.

The drainage rate, filtration resistance, and strength properties of the 635 freeness pulp (Sets 5 and 6) are shown to approximate those of the mill headbox stock and, on this basis, the 635 freeness stock would be considered a satisfactory secondary reference.

Results obtained in the second series with the 630 and 460 freeness pulps (Sets 13 and 14; Table IV) show reasonably good agreement with their counterparts in the first series and, hence, these pulps were tentatively accepted as replacements.

The beater adhesives examined thus far (Table V) provided rather substantial improvements in strength over the stuff box controls and two of these (Accostrength 90 and Kymene 557; Sets 15 and 23) afforded improvements of 22-29% over mill headbox controls. Contrary to normal experience, tear strength again increased with increase in other strength properties, thereby providing a rather unique combination of properties. This is further enhanced by the fact that the drainage rates at maximum strength were roughly comparable to that of the headbox stock. The expected advantage from the partially dispersed starch did not materialize but this may have been due to nonoptimum conditions and would probably warrant further consideration.

In review, the desired improvements in bursting strength have been achieved by two methods:

1. By refining the stuff box stock to an equilibrated freeness of 435 C.S.F. in which case the drainage properties were adversely affected, and
2. By incorporating 2% of beater adhesive into the stuff box stock in which case the drainage properties in the sheet mold were relatively unchanged.

Filtration resistance determinations on these pulps are incomplete and water removal measurements will be tentatively made as the final step in the current program. In the meantime, studies concerned with improving the drainage properties of the optimum strength pulp are underway. This work explores the effectiveness of selected drainage aids over a range of concentrations at two agitation rates. Further work with beater adhesives is also planned.

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LITERATURE CITED

1. Leech, H. J., Tappi 37, no. 8:343-9(Aug., 1954).
2. Casey, J. P., Paper Ind. 26, no. 10:1277-80(Jan., 1945).
3. Ingmanson, W. L., Tappi 35, no. 10:439-48(Oct., 1952).

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